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Department of Mechanical Sciences
December 6, 1968

Purchasing Office
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Reference: Contract No. NAS8-21133, SwRI Project 02-2119, Monthly Progress Report No. 19, "Minimum Pressure Loss in High Velocity Flow Duct Systems"

Gentlemen:

During the past monthly period, a portion of the time was used to plan the work for the initial phase of the year's extension of the contract, which has just been negotiated. Also, some rebuilding and updating of our experimental equipment was undertaken so that we can effectively perform the work required by this contract extension.

Initial Plans for Work on Contract Extension

For the benefit of the reader who is not familiar with the requirements of the contract continuation, several pages from the proposal for extension are attached, which describe the work to be done. We have divided the work into three phases which are:

Phase I - Water and air flow tests of selected bellows (including flexible hose), and corresponding appropriate analysis.

Phase II - Media investigation of bellows flow-induced vibration phenomena.

Phase III - Bellows damping investigation.

We intend to start immediately on the first phase of work, which calls for the water and air flow testing of a number of bellows, plus any corresponding analytical work which is needed. Within the next week, the required bellows specimens will be ordered; however, prior to the receipt of these new bellows we can begin the flow testing of several bellows already on hand which were not previously tested. The following outlines a typical test series for a given bellows specimen:

(a) Pretest preparation and inspection, consisting of strain gage installation, determination of spring rate, and deflection test to obtain stress-deflection relationship. In the past, we have always obtained the actual spring rate, and used this value in calculating bellows resonant frequency and in checking existing bellows spring rate equations. In addition, as noted above, we now intend to also get a convolution stress-deflection relationship; this will be very useful in flow-induced vibration data reduction and, further, will allow us to determine the validity of existing bellows stress-deflection analyses.

(b) Bellows damping will next be determined for each specimen as a result of a forced excitation test. This test will involve mounting each specimen on an electromechanical shaker in an appropriate fixture, and obtaining a plot of stress as a function of frequency for a given base input acceleration amplitude; from this plot the bellows damping can be determined. This damping value is important for correlating the analytical predictions with the experimental results.

(c) Air flow testing will next be performed on each bellows specimen. Because our air flow test facility has a variable pressure capability, each bellows will be tested at several static pressure levels. This will allow the effect of gas density to be assessed. The instrumentation used will include strain gages, pressure transducers, microphones, and accelerometers.

(d) Water flow tests will conclude the testing with each specimen; these tests are last since it is anticipated the fatigue failure problems of the bellows will be, in general, most severe with water as the flowing media. Of course, some failures may occur during the air tests. The instrumentation of the bellows for the water flow case will be the same as with air flow.

In addition to the above tests, we have planned some supplementary experiments which are designed to find out more about the nature of the vortex shedding excitation mechanism. For example, more experiments will be carried out with the variable-convolution-geometry vibration test model, which has been described in previous reports; this model, it may be recalled, allows force coefficient data to be obtained.

Experimental Equipment Updating

Three different flow facilities will be used for the Phase I work; first, a closed loop gas flow system, second a small water flow loop, and finally, a large water flow loop. Figure 1 is a sketch of our newly built gas flow facility which has an estimated flow capacity of 15 to 20 cubic feet per second. This system can be operated over any static pressure range from a fraction of an atmosphere to about six atmospheres or 100 psi. Flow rate metering will be accomplished with a calibrated orifice, and a heat exchanger has been incorporated into the system to allow control of temperature. Figure 2 is a sketch of the small water flow system; this system is essentially the same as our previous water facility except that it has been rebuilt to incorporate a larger pump with about 50 percent more capacity (about 800-1000 GPM) than the original pump. The system piping has been changed to allow higher working pressures, and the configuration has been generally "cleaned up". This system will be used to test bellows up to about 3 inches I.D. The above two facilities will be put to immediate use on the Phase I work. Figure 3 shows the larger water flow loop which will shortly be constructed with in-house funds; this system is adequate in capacity to test the largest bellows (6 inches I.D.) which we anticipate will be investigated.

Anticipated Progress

During the following monthly period, the Phase I testing will be initiated and significant test data should be available in time for the next monthly report.

General

Copies of this Monthly Progress Letter are being distributed according to the approved distribution list which is enclosed.

Respectfully submitted,

C. Richard Gerlach
Project Manager

CRG:ac

Enclosures: (3) ccs
Distribution List
Figures
Exerpt from Proposal for Extension

cc: According to attached distribution list
Mr. Roy T. Bowen, DCASO, San Antonio
Mr. A. C. Hulen, SwRI (2)

APPROVED:

H. Norman Abramson, Director
Department of Mechanical Sciences

Work for Continuation of Contract NAS8-21133

The following pages were taken from the proposal for continuation of Contract NAS8-21133, 18 October 1968, and describe the work to be accomplished.

III. PROPOSED PROGRAM

III. 1 Objectives and Scope of Work

As specified in Exhibit B of the RFQ, the purpose and the Scope of Work for the continuation are as given below:

> The purpose of this program is to perform theoretical and experimental investigations of stress in bellows components as a result of flow excitation.
>
> Handbook information such as formulas, curves, numerical tabulations, etc., shall be generated to provide the Engineer with a means of predicting the fatigue life of bellows components in fluid flow systems.
>
> Emphasis shall be placed on the resolution of flexible metal hose fatigue failures. Methods of damping, new design concepts, limitation of application, etc., shall be investigated. Damping factors shall be determined for multi-ply bellows and braid in relation to single-ply bellows.
>
> Media investigations shall be made to determine the relative "damping" of gases and cryogenics to that of 70° water or air. Range of temperatures shall be: Gases -380°F to 150°F; Cryogenics -423°F and -320°F. Pressure ranges shall be: Gases -100 PSIG to 3200 PSIG; Cryogenics -50 PSIG to 400 PSIG.

In order to satisfy the above stated objectives and work statement, the actual work which we propose to carry out can be broken down into three separate phases; these are:

A. Water and air flow tests of selected bellows (including flexible hose), and corresponding appropriate analysis.

B. Media investigation of bellows flow-induced vibration phenomena.

C. Bellows damping investigation.

Each of these phases is now discussed in some detail.

III.2 Water and Air Flow Tests, and Appropriate Analysis

In this phase, a number of hose and bellows test specimens will be purchased and flow tested with both air and water. In addition, analysis will be carried out, based on the results of the present study, and the experimental and analytical data will be utilized in a number of ways. First, the critical flow ranges predicted for each component will be verified; this means that the bellows resonant frequencies and the vortex shedding frequencies will be calculated and used to define critical flow ranges for comparison with test observations. Any new modes of vibration not predicted by the present analysis will be appropriately dealt with. Second, the observed flow induced stress will be compared with the stress predicted from the analytical work; also, further consideration will be given to the "stress-indicator" semi-empirical factor which is useful for supplementing the more precise analytical methods. Third, comparison of these bellows tests and the analysis will give one means of comparing the relative damping of various configurations under actual flow excitation conditions. Fourth, the results of this phase will be useful for comparing various bellows monitoring techniques.

For these water and air flow-induced vibration tests, a number of carefully selected bellows specimens will be purchased. These new bellows will be in the size range from about 2 to 6 inches for the water flow tests, and about 1/2 to 4 inches in size for the air tests. Both free bellows and flexible hose will be purchased for test; also, each specimen type will be obtained in 1, 2 and 3 ply configurations where possible. The actual number and variety of bellows purchased will depend largely on the available funds and the final selection will be subject to the approval of the NASA Technical Monitor. We suggest, however, that the items listed below be acquired and tested.

Free Bellows
- 1 inch I.D.
- 2 inch I.D.
- 4 inch I.D.
- 6 inch I.D.

All in 1, 2, and 3 ply

Flexible Hose
- 1/2 inch I.D.
- 1 inch I.D.
- 2 inch I.D.

All in 1, 2, and 3 ply

All tests will be conducted in a manner such as outlined below:

(A) Each bellows or hose will be instrumented with strain gages in appropriate locations.

(B) Next, the bellows will be mounted on an electro-mechanical shaker and a forced response vibration test will be performed; this will give the bellows damping.

(C) Finally, the test item will be installed in the flow facility and flow tested. The instrumentation involved here will give strain, acceleration, acoustic and pressure data.

One aspect of the analysis performed in this phase will involve a verification, from the test results, of the bellows critical frequency prediction method which is already developed. Another aspect will be to continue the work presently under way which is directed at coming up with actual bellows flow-induced stress. A final aspect of the analysis will be to further pursue the simple "stress-indicator" correlation parameter.

III. 3 Media Investigation

The objective of this phase of the work is to determine what effect flowing media, other than water and air, have on the flow-induced vibration phenomena. Since we presently believe that bellows damping and, to some extent, the bellows resonant frequency (coupled fluid-structural frequency) are the primary variables affected by changes in the fluid media, much of this aspect of the program will be accomplished with forced excitation tests. This means that special test fixtures will be constructed so that the various bellows can be mechanically excited, as illustrated in Figure 6. With properly designed fixtures, we will then be able to obtain forced response data for several modes of vibration, with various fluid media contained within the bellows. For example, one series of tests might involve liquid nitrogen at various pressures as the internal media; the external environment could be ambient air, or other gases, such as helium, or possibly even a vacuum.

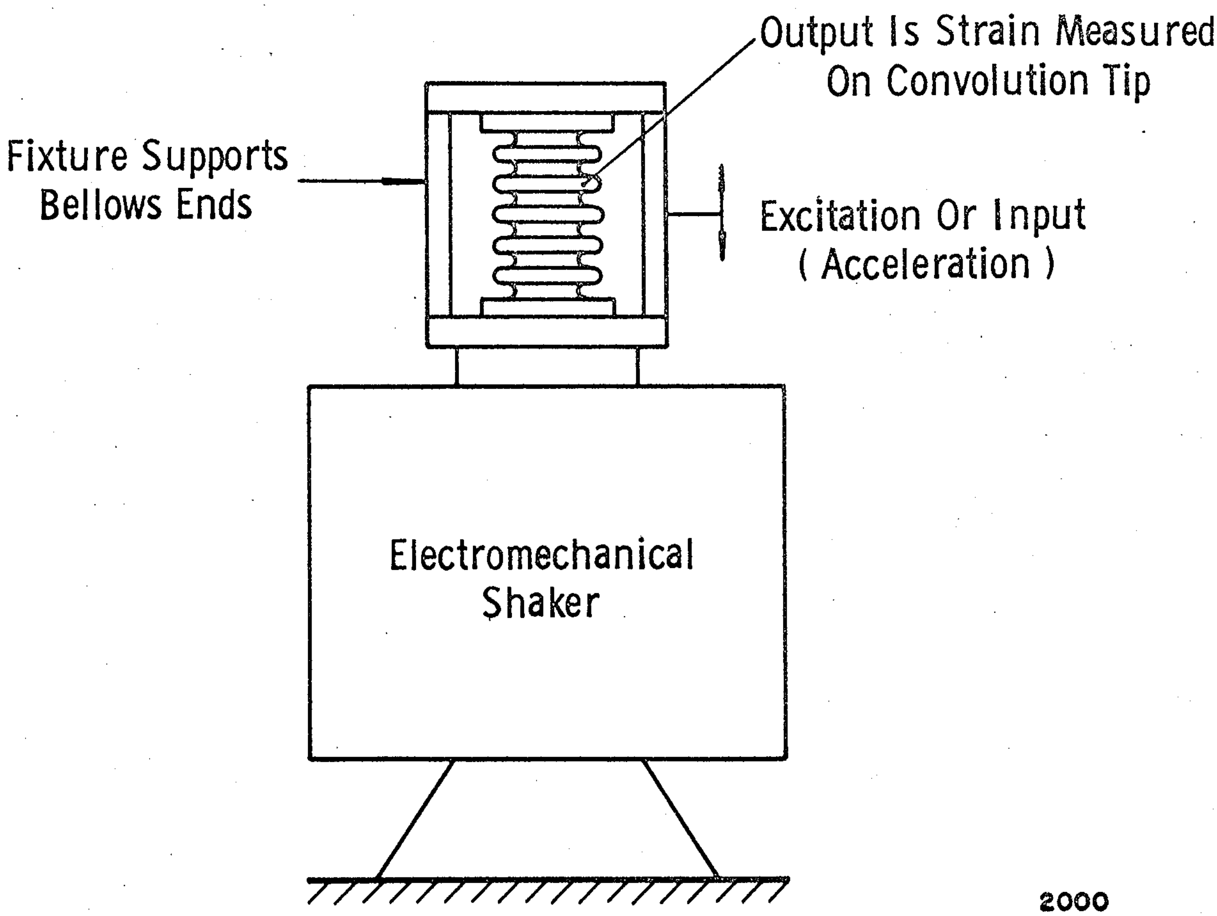

Figure 6. Schematic Of Bellows Damping Measurement Test Setup

We believe that conducting part of the media investigation in the manner generally described above will be particularly advantageous from a cost standpoint (resulting in a considerable cost savings over corresponding actual flow tests).

The forced excitation tests will be supplemented by some small scale flow tests to further study the effects of various flowing media. We intend to set up a small cryogenic flow loop for this purpose; in addition some testing will be done with our small gas facility with gases other than air, for example, nitrogen and helium. High pressure gas tests can be performed on a small scale with a simple blowdown system.

In summary, this phase of the work will be designed to determine how the frequency and stress prediction methods must be compensated to account for media effects.

III. 4 Damping Studies

This aspect of the proposed study will be directed to an investigation of concepts for preventing bellows fatigue failures by use of special damping devices.

In general, there are two classes of devices for suppressing the bellows vibrations; these are (1) devices which prevent vortex shedding from the convolutions, and (2) devices which add damping to the bellows structure. To suppress vortex shedding, liners are generally used, and further effort can well be expended in this area, with emphasis on correct liner design to reduce pressure loss and prevent liner failures, i.e., buckling, splitting and tearing loose. In addition, we intend to further study means of providing more bellows structural damping. Some possibilities here are: (1) the use of special damping springs in the convolutions (we have already shown this to be a valid method by actual testing), (2) foams applied externally, and (3) special coatings on the outside of the bellows, including on the interface between plys for multiple ply bellows.

Under the present study, we have tried several damping ideas, most of which were successful. The major problem is to come up with a method which is successful over a broad temperature range, including extreme cryogenic temperatures.

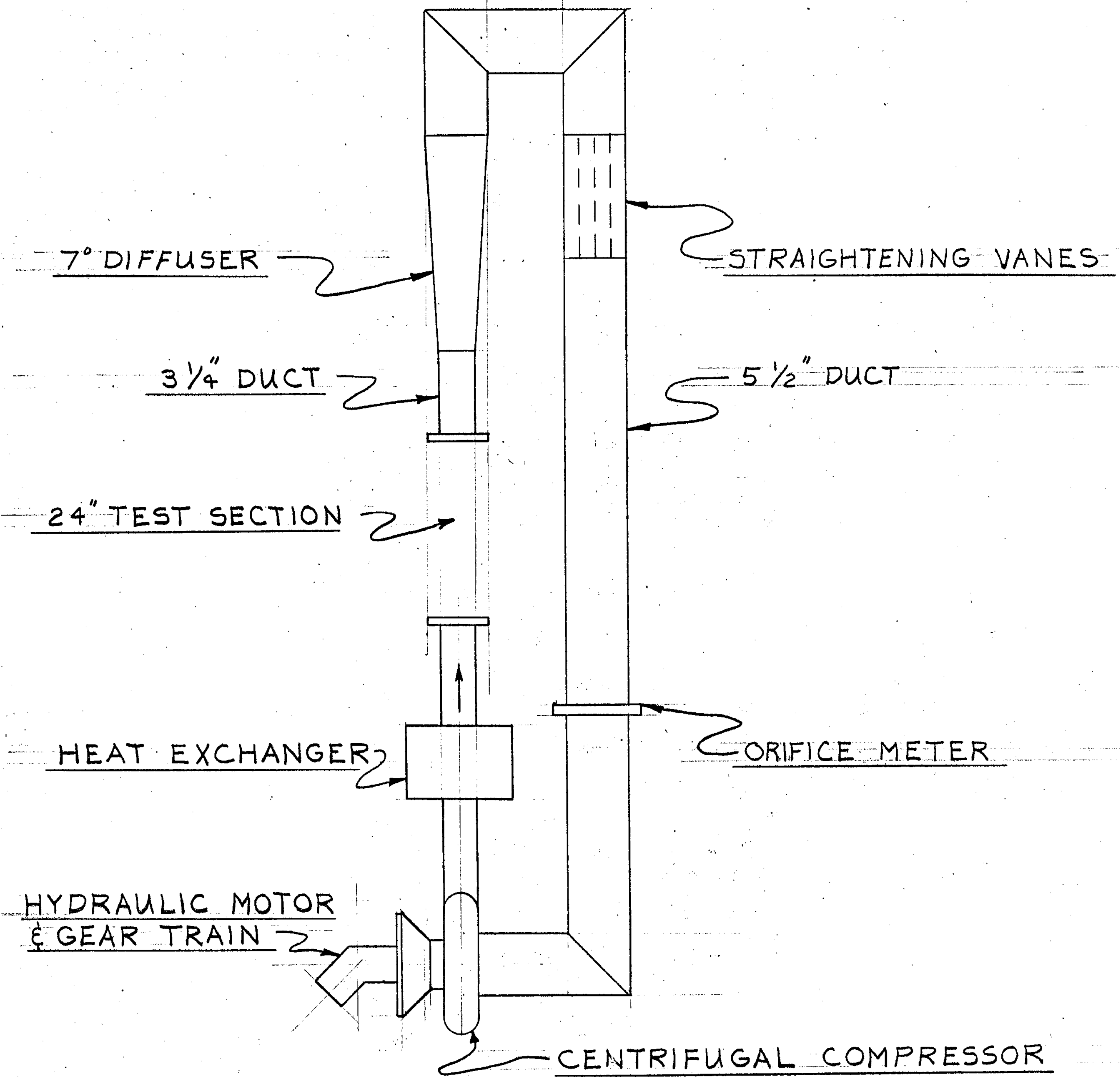

FIGURE 1 VARIABLE PRESSURE GAS FLOW FACILITY

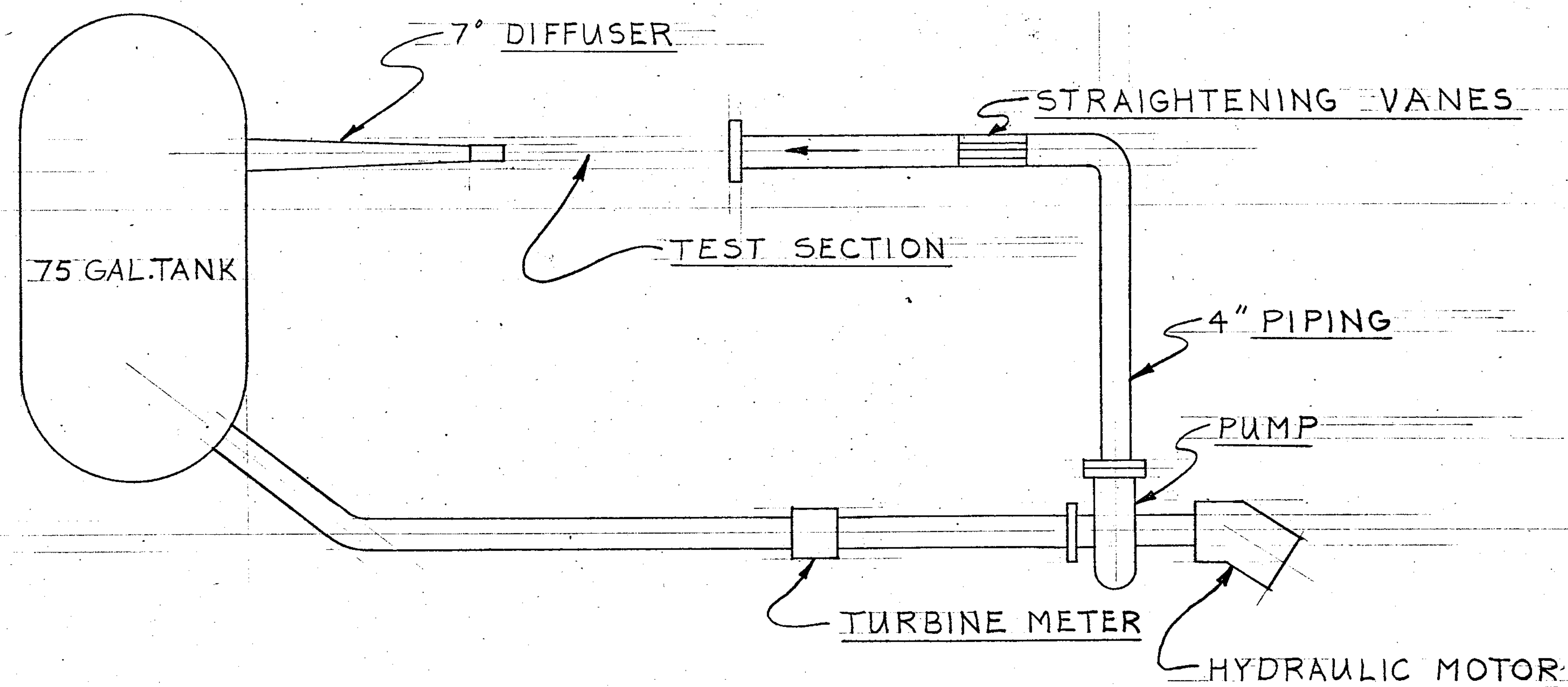

FIGURE 2 SMALL WATER FLOW FACILITY - MODIFIED CONFIGURATION

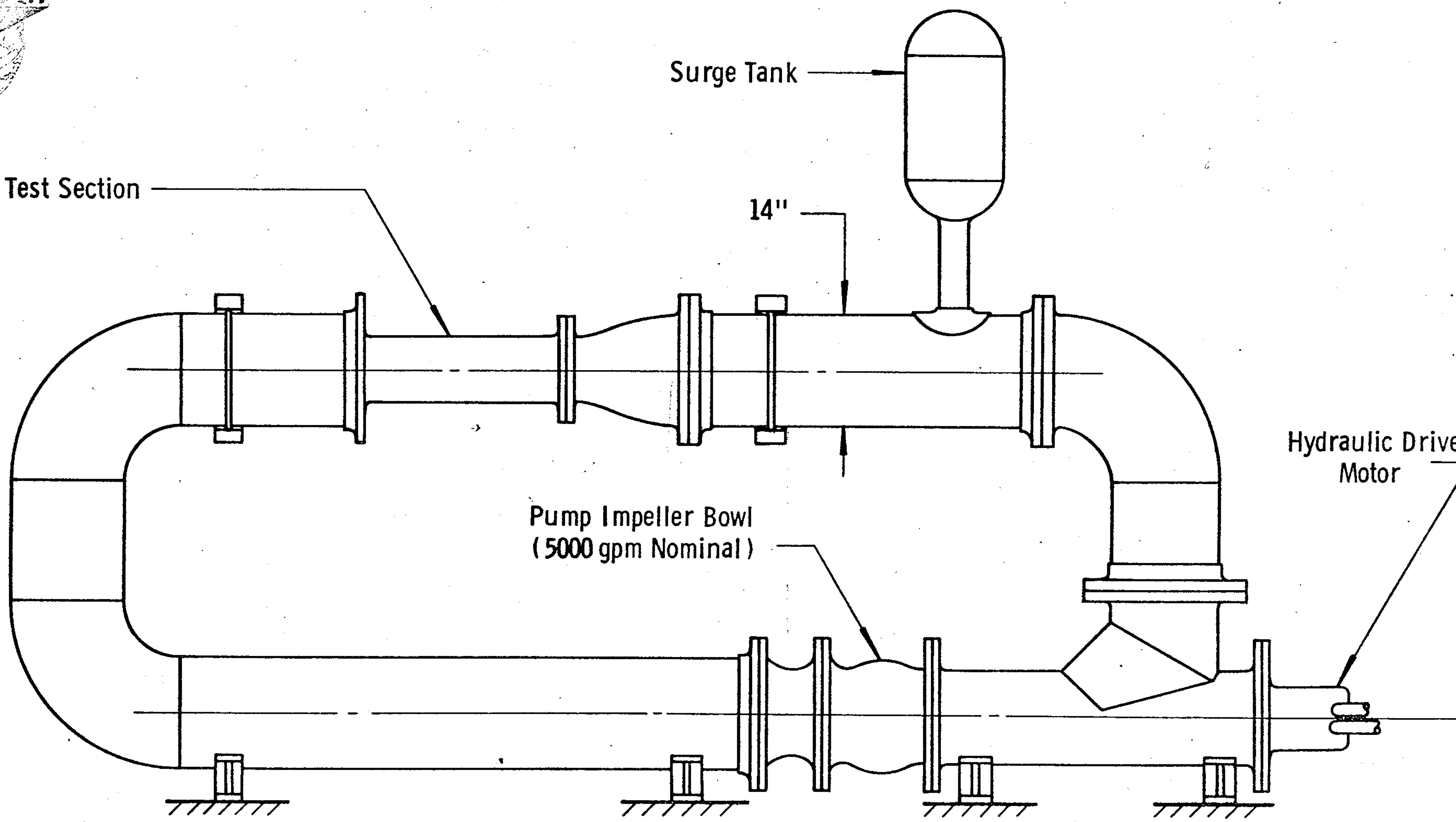

FIGURE 3 LARGE WATER FLOW SYSTEM